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Procedia CIRP 41 (2016) 478 – 483

www.elsevier.com/locate/procedia

48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015

Semantic information modelling for factory planning projects

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Abstract

Nowadays, one of the main challenges in factory planning is the consistent and coherent information processing along planning processes. Despite the current efforts in the fields of Virtual Production and Digital Factory, planning and simulation applications mostly support only analyses and optimizations of single planning aspects. To match nowadays challenges, planners require solutions that provide an integrated view on all data generated along planning processes to evaluate planning scenarios in advance and to achieve increasing production quality and efficiency. We have developed an essential solution by combining the 'Condition Based Factory Planning', a flexible planning approach which decomposes the process into standardized planning modules, and the 'Virtual Production Intelligence'. This fusion creates a basis for the integration and analysis of data aggregated along production (planning) processes. The current information model provides factory planners to perform integrated analyses of process characteristics on the bases of module parameters to increase transparency of information flows.
In this paper, the enhanced process of semantic information modelling is described to integrate precise planning values within a factory planning project from heterogeneous data sources and to provide a consistent information base within the planning system. Therefore, we define the relevant concepts of the domain and their interrelations in a formalized and explicit way. Furthermore, specific templates for the planning modules are developed to ensure the completeness and high data quality which are then mapped against the information model by means of semantic annotation and interpretation. This approach provides semantic interoperability of planning and simulation applications used in factory planning without the need to change their individual data models and structures. Thus, the business logic of the domain and the technical implementation of the planning system are decoupled which provides a generality of the business logic and a flexible adaption of planning modules.

Peer-review under responsibility of the scientific committee of 48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015

Keywords: Virtual Production Intelligence; Semantic Information Model; Ontology; Factory Planning

1. Introduction

Nowadays, companies especially in high-wage countries are faced with the challenge to offer customized and high-quality products at feasible costs despite of the increasing complexity of production processes and the large number of production parameters [1]. In particular, the process of factory planning is assuming a decisive role as it forms the basis for later production in many ways. Thereby, progressive methods for a cost- and resource-efficient planning and product development are helping to design the required planning processes in a tailor-made and modular way. Furthermore, the continuous optimization of factory planning processes, a flexible adaption to short-term changes as well as a consequent value-orientation of the planning processes are indispensable [2].

Current factory planning approaches are usually based on the experience of planning experts from different domains to manage the various number of challenges and requirements of planning process. In terms of an efficient and result-oriented process development, they have to closely cooperate and continuously exchange data and information with each other. Generally, they are supported by several technical planning applications that are based on heuristics and qualitative

Peer-review under responsibility of the scientific committee of 48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015
doi:10.1016/j.procir.2015.12.022

evaluation criteria and that are designed and optimized for specific applications [3]. Due to varying data formats and data models of the applications that have been independently arisen for historical reasons, a large number of so-called stand-alone solutions exist in practice. In order to allow an effective and integrated handling of planning data within a structured information model, the challenge is to integrate existing stand-alone solutions of planning and simulation applications within the domain of factory and production planning in such a way that a comprehensive evaluation of planning scenarios becomes possible [4].

In the context of the D*igital Factory*, such efforts are subsumed under the concept of V*irtual Production*, a simulated networked planning and monitoring of production processes using digital models [5]. The fundamental idea of the virtual production is to reach interoperability of the mentioned heterogeneous IT applications which has not been achieved so far [6]. In recent years, several approaches have been developed to overcome the problem of heterogeneity of the applications used. Besides the paradigm of standardization, in research approaches are pursued to reach interoperability of distributed, heterogeneous planning and simulation applications by means of integration techniques. In the field of semantic technologies, especially the Semantic Web, promising approaches have been developed that are based on information and application integration as well as the use of ontologies [7].

Based on these research works, the concept of the *Virtual Production Intelligence* (VPI) along with the central component of the adaptive information integration and the technical implementation of the VPI platform has been created [8,9]. VPI transfers basic intelligence concepts in terms of integration and analysis of data generated along business processes to the domain of virtual production. Within the domain of factory planning, we have already presented an application in [10] with the objective of a continuous data and information management for the *Condition Based Factory Planning (CBFP)* approach.

In this paper, we present the general processes of information modelling and semantic annotation of the VPI approach and the implementation within the mentioned application in factory planning to integrate data from heterogeneous planning and simulation applications. The concept focusses on the setup of a domain-specific integrative information model which provides the possibility of an integrated analysis of process characteristics and an improved decision support.

To reach these objectives, the following research questions will be answered in this paper:

- How can the relevant concepts of the domain of factory planning and their interrelations be formalized in an explicit way?
- What are the necessary steps of modelling and integration to provide semantic interoperability of planning and simulation applications used in factory planning?
- What are the main relevant concepts of the domain of factory planning to be considered during information modelling?

2. Related Work

Information modelling is the basis of each information system when providing technical functionalities to satisfy specific information needs of a certain task and user. This process can be arranged into the overall context of information management by regarding an adapted information management cycle as presented in Fig. 1. The figure shows the main principles to implement a new domain or to extend an existing one. Starting with the identification of the information user, information needs are identified and gathered that are not satisfied in the current information infrastructure. Afterwards, possible data sources are identified and integrated into the information structure. This is realized by providing access as information resources. Furthermore, domain-specific analysis and evaluation methods are used to enrich existing information. The user triggers and controls the analysis via an information product. Within this paper, we focus on the process of integration.

Thereby, in recent years a wide variety of solutions such as Enterprise Application Integration (EAI) has been developed with regard to information integration and application integration that are distinguished in this domain. These technologies are particularly necessary in the domain of factory planning where relevant data sources have been historically and individually grown. The consolidation of information from different data sources with normally diverse data structures is referred to as information integration, the consolidation of whole IT solutions along business processes as application integration [7]. We concentrate on the information integration and especially on the materialized integration – in contrast to the virtual integration – where data from sources are loaded, cleansed and stored in a central data storage [12]. The objective is to generate a consolidated information base to provide an efficient and effective access to information which is only possible to a limited extent in terms of a direct access to the original data source [7].

Here, the data exchange is based on diverse data formats and structures. Primarily, computer-aided technologies (CAx) and Enterprise Resource Planning (ERP) systems with different open and proprietary data formats serve as data sources. In practice, office solutions such as Excel, Word, or PowerPoint are widely used as generator systems in product and production development to calculate and visualize quantitative parameters based on a comprising set of data [4].

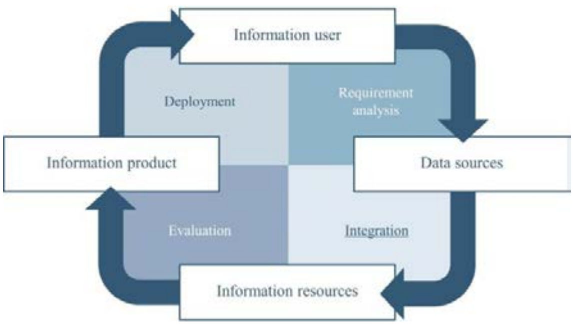

Fig. 1. Information management cycle adapted from [11].

To realize the discussed information integration, an extended consideration of information modelling is essential. “Information modeling is the cornerstone of information systems analysis and design. […] Information modeling is the process of formally documenting the problem domain for the purpose of understanding and communication among the stakeholders” [13]. An Information model, the product of the modelling process, provides the basis to explicitly formalize concepts, relationships, and constraints as well as correlations and dependencies of the domain. By means of classical modelling languages such as the Entity-Relationship Model (ERM) [14] or the Unified Modeling Language (UML) [15], concepts and relations are identified and visualized. To provide access to the information model not only for the business user but also for the technical system, the model is to transfer to machine-readable formats. Thus, the information model can be embedded in the information system.

Therefore, the objective of semantic technologies, especially Semantic Web technologies, is to formally represent domain-specific concepts within the technical system to realize an improved interchangeability and usability of data [16]. Thus, the simple machine-readability of classical modelling applications does not go far enough. It is necessary to provide machine-interpretability, a functionality that is offered by semantic technologies especially ontologies. Ontologies thereby offer the possibility to formally and explicitly specify concepts and their relations [17]. In the last years, diverse recent modelling languages have been developed by scientists to represent and specify ontologies [7]. A widely used representation is the Web Ontology Language (OWL) [18] that we also apply within the VPI for the representation of planning information.

Based on the described techniques of knowledge representation, one aim of the current research in factory planning consists in systematizing the knowledge of experts. Again, information modelling is the fundamental approach. Within the EU-project *Virtual Factory Framework* an information model has been set up by means of several ontologies to realize a functional virtual model of a real factory [19]. The developed *Virtual Factory Data Model* comprises a framework which provides a common definition of data that is shared among the considered software applications. Furthermore, several information models have been developed over the past few years focusing different aspects of factory planning and in varying levels of detail. E.g. in [20] an information model for factory layout planning is developed to structure and represent information and knowledge while in [21] the abstract information for the integration of factory planning and factory operation have been modelled. All these approaches provide advanced concepts using mostly classical modelling languages. Hence, instead of integrating the information model as a central component into the technical system, the information model only serves to define a common language between engineers and business users and to derive the logical data model. Hence, the presented approaches are not practicable for the desired support of factory planning projects by means of a semantic modelling within an integrative information system.

3. Semantic Information Modelling in Virtual Production Intelligence

3.1. Application scenario ‘Condition Based Factory Planning’

Virtual Production Intelligence designates our concept that enables product-, factory-, and machine planners to plan products and their production collaboratively and holistically [9]. The concept comprises methods to consolidate and propagate data generated in the domain of virtual production. Furthermore, it includes visualization and interaction techniques to analyze and to explore the retrieved information. We chose the term following the original idea of business intelligence systems with regard to virtual production. Virtual Production Intelligence refers to the mentioned concept of an integrated handling and analysis of information generated in the context of virtual production.

To demonstrate the concept of Virtual Production Intelligence and our information product – the VPI platform – in the application domain of factory planning, we implemented a VPI driven information system to support the Condition Based Factory Planning approach [10]. The main idea of CBFP is the modularization of different planning tasks not with regard to a temporal chronology but with regard to their contents [22]. Hereby, a module encloses a single planning task with defined input and output information, respectively parameters (Fig. 2). These parameters contain the actual planning information. Hence, the CBFP is object-oriented and much more flexible than the established but rigid planning procedures.

So far, the CBFP approach, as described, provides a construct for the information flow. Furthermore, it provides the basis for an information model describing the necessary and the optional information as well as their relations along the planning process. Therefore, different types of information are differentiated:

- *Input information* of a module that is a planning result (output information) from a previous one
- *Input information* that has to be generated before starting with the planning task of the module (e.g. by data export from ERP system, by expert interviews, or by workshops)
- *Output information* is the result of a certain planning module, generated in the end of the planning step, and used in further modules or as a final planning result

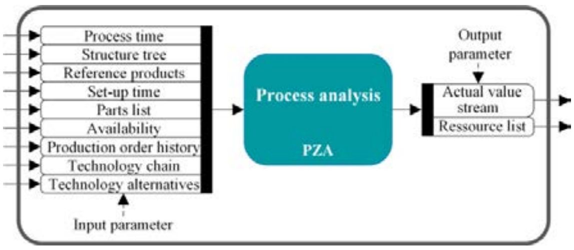

Fig. 2. CBFP module ‘Process analysis’.

This overall landscape of modules is the basis for an IT based analysis of the planning process. Still, the management of the data and the pieces of information within a precise planning project is very complex. CBFP does not provide an information system to support the planner on a data level. There is distributed data storage within the individual planning and simulation applications. Hence, the transfer of data between the sources in order to perform an evaluation is time-consuming and error-prone.

Therefore, we realized the coupling of the CBFP approach and the VPI, which has been introduced in [10]. The objective is a continuous and consistent information modelling along whole planning projects to support planners with methods for automated information evaluation and analysis. Thereby, firstly seven CBFP planning modules from the area of production structure planning are considered. The main challenge is to reach interoperability of the heterogeneous data sources by information integration techniques. Both processes of information modelling and integration are presented in the following sections.

3.2. The process of information modelling

The general process of information modelling that we pursue consists of the following four steps:

1. Definition of the domain-specific information model
2. Explicit formalization of the concepts, relationships and constraints within a domain ontology
3. Derivation of the logical data model of the concrete application
4. Derivation of validation rules for consistency checking

The first step of the modeling process comprises the definition of the information model of the respective domain, in our case the domain of factory planning. By means of analyzing the identified data sources and performing interviews with domain experts, the objective of the information model is to reach a common language and understanding of the concepts used in the domain. Therefore, the model is firstly created and visualized by classical modelling languages.

To reach the desired machine interpretability of the business logic of the domain, the concepts, relationships and constraints are explicitly formalized in the next step by means of the semantic technology of ontologies. Besides of structural ontologies, the main part consists of the domain ontology. Through this, description logic based reasoning becomes conceivable so that the automatic identification of constraint violations and the extraction of unspecified but implicitly valid information by the system become realizable.

This generic information model is the starting point for the logical data model of the concrete application which can be derived from the information model. As a next step, the mapping between the ontology and the logical data model is defined, to assign concrete data to the corresponding concept of the information model directly. Therefore, the data model defines the object-relational mapping e.g. by concretizing many-to-many relationships of the information model. Within this step, the implicit information of the domain ontology gets lost, as it cannot be represented within the data model.

However, the constraints and relations within the information model allow the extraction of validation and consistency rules that we use to realize a consistency check of the planning data during the integration. This process is fully automated so that the integration process automatically adapts to changes in the information model (and the corresponding changes required in the underlying data model). Hence, we can ensure high data quality within the information base of the VPI platform as the integration process only completes if no consistency violations occur.

Based on this generic process of information modelling, the precise process of information integration of planning data from the sources within the specified application scenario is described in the following section.

3.3. The process of information integration

After having completed the modelling process, the baseline is created to realize the integration of the different data sources. Again, this process is divided in the following three steps:

1. Definition of standardized data sources for all parameters
2. Implementation of the integration of each data template
3. Storage and visualization of data within the VPI platform

The first step comprises the definition of standardized data sources for all parameters and corresponding information. This shows a high potential for the data management efficiency within planning projects and also for the knowledge management regarding several projects within a company. Current factory planning departments often face troubles with an inconsistent data management due to several reasons: application of different software applications along the planning process, insufficient documentation within the project, use of different data templates, etc. This leads to higher planning efforts and a lower learning curve between two projects.

To overcome these challenges, data sources for all information within the planning landscape of CBFP are defined which is based on the experience of factory planning experts. Therefore, common export interfaces or specific templates for Microsoft Excel as widely used planning application serve as data sources, in order to satisfy the business user requirements. By analyzing the data structures of several projects in the past and further optimizations, the basic templates are identified. The single templates hereby fulfill the following requirements:

- Completeness: Templates have to cover all necessary information to fulfill the required planning task
- Exclusiveness: The different sub-information of an overall planning information must be exclusive and not redundant
- Specificity: All information in the templates must be clearly defined and specific so that a planner or user of the application can directly fill in the template

After having identified the relevant templates for the planning information in a first draft, templates and the overall planning landscape were analyzed regarding the mentioned three requirements in total. Especially the exclusiveness is an important challenge as redundancy and doubled information often lead to incoherent data structures and multiple data management. Thus, besides the consistency checking during the integration process the adequate definition of data sources already provides high data quality.

Based on these sources, we use the technology of adaptive information integration in terms of the actual integration process which provides several integration services with two main functionalities [8]: Firstly, the services facilitate the autonomous extraction, transformation, and loading of data from the data source into the information base. Secondly, they map the loaded data automatically to the corresponding concepts of the information model and enrich the data with the implicit information of the ontology. This process of semantic annotation is followed by the already mentioned consistency checking. In case of inconsistent data or other unexpected problems, the user interface informs the business user. In case of a successful integration instead, the integrated data is loaded automatically into the user interface that provides visualization and interactions for a further analysis.

This approach provides the ability to connect different kinds of data sources to the VPI platform without being reliant on standardized data exchange formats. This is to reach a consolidated information base along the entire planning process. In terms of the following evaluation and visualization, the planning information and the corresponding templates were analyzed regarding possible visual illustrations of the data within the VPI platform. E.g. a product structure can be represented by means of a simple data view or it can even be visualized as a product structure tree, which helps the planner to understand the gathered information much faster. A more detailed discussion of the evaluation and visualization techniques of the VPI platform is not part of this paper.

4. Results

As described in section 3.2, the first step of the modeling process is the definition of the information model of the respective domain. Therefore, based on the abstract information model of the CBFP, we analyzed the different data sources and conducted interviews with domain experts. The result is the explicit specification of the vocabulary and the valid constraints of the specific domain, which we generalized to a generally accepted model. This is firstly modeled in an UML class diagram (Fig. 3). The figure shows the main concepts of the domain of factory planning at the highest level including their relationships. Further, we describe each of these concepts by additional meta-attributes and detailed the information model, which is not shown in the figure.

Afterwards, we formalized the information model as an ontology using the Web Ontology Language (OWL). At first, we defined a formal (upper-level) ontology as a template to create specific domain ontologies that are based on the same concept-, relationship-, and attribute types. Thereon, we transferred the domain-specific information model for factory planning shown above to an ontology. Additionally, we formalized the abstract information model of the CBFP as another ontology with the two base concepts *module* and *parameter* (Fig. 4). Besides, the figure shows the relation between modules and parameters and precise individuals in terms of parameters of the module *Process analysis* from Fig. 2. By that ontology, we can validate the structure of a planning project, when creating it by means of the VPI platform. Thereby, we decouple the business logic of the domain and the technical implementation of the planning system within an application scenario. This procedure provides a generality and transferability of the business logic and a flexible adaption of planning modules and data sources.

The integration and validation process of planning data as described in section 3.3 can be triggered within the VPI platform, which is accessible via smartphone, tablet and personal computer. For each module and parameter, the planner can upload the corresponding data source with the standardized data templates to the platform and start the integration process (Fig. 5). The list on the left side contains the enabled modules and parameters of the planning project. By selecting one of the modules, the user can view the module structure and manage the data integration on the right side. Furthermore, since the automated integration process has successfully completed, the user can directly access the data and start the evaluation, which is indicated with the exemplary product structure tree downright.

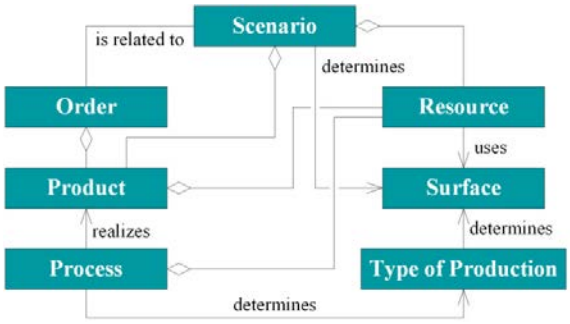

Fig. 3. Main concepts of the information model for factory planning.

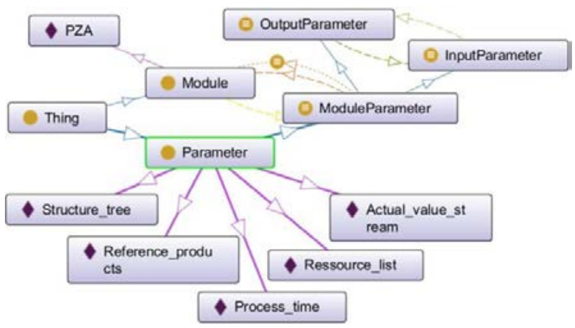

Fig. 4. CBFP ontology with selected individuals.

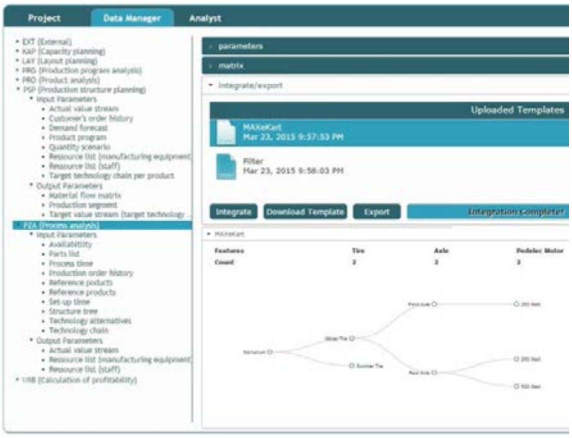

Fig. 5. VPI platform for factory planning.

5. Conclusion and Future Work

In this paper, we have presented the underlying processes of information modelling and information integration of the Virtual Production Intelligence concept considering the application of providing a continuous and consistent information management for the Condition Based Factory Planning approach. The focus was on the semantic annotation of planning data by an explicit formalization of the concepts, relationships and constraints within a domain ontology.

For a unified access to all data generated within a planning project, the VPI platform offers an added value by providing information integration and evaluation processes for all sources. Based on the semantic information model, data is automatically validated during the integration to ensure high data quality. The resulting consolidated information base enables planners to perform various evaluations that are not possible so far.

In the next steps, we will complete and validate the information model in the mentioned application scenario. The objective is to integrate all relevant data of one factory planning project in order to provide a full information base. Furthermore, additional modules of the CBFP will be integrated to model any kinds of factory planning projects. At the same time, we will improve analysis algorithms, develop further KPI for information evaluation, and enhance the visualization by means of a KPI-cockpit and visual analytics techniques. Finally, the VPI platform will be used in actual factory planning projects to evaluate the improvement in decision support.

Acknowledgements

The approaches presented in this paper are supported by the German Research Foundation (DFG) within the Cluster of Excellence “Integrative Production Technologies for High-Wage Countries” at RWTH Aachen University.

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